Homework 3

AST 301, Section 45940, Spring 2004

NAME | Student EID | Score: /100

Due Tuesday, April 6, 2004

## A. – THE AGE OF THE UNIVERSE

In this homework, believe it or not, you are going to estimate the age of the Universe. But don't worry, I will guide you through the arithmetic.

Let's pretend that you just came back from an observing run at McDonald Observatory in West Texas. There, you took pictures and spectra of the brightest galaxies in four clusters, Virgo, Ursa Major, Corona Borealis, and Boötes. The pictures and spectra are shown on p. 294 of Edition 6 or p. 296 of Edition 7 of the textbook (ignore the Hydra cluster and note that the $7^{\mathrm{th}}$ Edition has screwed up the name of the Corona Borealis cluster – they call it Comoa Bonalis). **The textbook's answers to some parts of this question are printed in the figure. Ignore these and derive your own answers. Of course, it is OK to compare your answers to the book's to help you not to make mistakes. But don't fiddle your numbers to agree exactly with the book.**

First, let's estimate the distance to each galaxy. It is not a bad approximation to assume that they are all the same size. Also, we'll assume that the pictures are printed at the same magnification, except for Virgo. The galaxy in Virgo was shrunk by a factor of 3 so it would fit. Now, if you measure the size of the image of each galaxy (it is best to use a millimeter ruler), and if the Virgo galaxy is (for example) 20 times bigger than the galaxy you are working on, then that galaxy is 20 times as far away as Virgo. Someone has already measured the distance to Virgo and told you that it is 17 Mpc. Notice that some galaxies are round and others are not. So, measure the longest diameter of each galaxy (in mm) and write the answer in the second column of the table on page 2. Then measure the shortest diameter and write it in the third column. Average the two measurements and write the answer in the fourth column. Don't forget to multiply the answer you get for Virgo by 3. Note: You will have to be very careful with the Corona Borealis and Boötes clusters because they are so tiny. **I recommend that you increase the accuracy of your measurements by enlarging the figure to full-page size using a xerox. If you do this, be sure to include the xerox with your homework.** (5 points)

Now you can estimate the distance to each galaxy from its size, from the size of the Virgo galaxy, and from the distance to Virgo. Write the answer in Mpc in the fifth column of the table. (5 points)

| Galaxy in | Longest diameter (mm) | Shortest diameter (mm) | Average diameter (mm) | Distance (Mpc) | redshift (mm) | redshift (Å) | redshift km/s |
|---|---|---|---|---|---|---|---|
| Virgo | ______ | ______ | ______ | 17 | ______ | ______ | ______ |
| U Major | ______ | ______ | ______ | ______ | ______ | ______ | ______ |
| Cor Bor | ______ | ______ | ______ | ______ | ______ | ______ | ______ |
| Boötes | ______ | ______ | ______ | ______ | ______ | ______ | ______ |

Next you need to measure how fast each galaxy is moving away from us. You do this using the spectra, by measuring the redshift of the strongest spectral lines, the H and K absorption lines of Calcium. You can see them near the left (blue) end of the Virgo spectrum, labeled by vertical blue lines. They are progressively farther to the right in each succeeding spectrum, and just past the middle of the Boötes spectrum. Your measurements are helped by the notes you made during the observing run: You already drew an arrow on each spectrum from the unredshifted position of the lines to the redshifted position of the lines. So you can measure the redshift in mm on the spectrum just by measuring the lengths of the arrows. Write the answers in the 6th column of the table above. (5 points)

To convert the shift from mm to Ångstroms, you would normally use a comparison spectrum of an fluorescent lamp. Unfortunately, the textbook version of the figure has cropped off the comparison spectra. So I will tell you the dispersion: it is about 35.7 Å per mm in the $6^{th}$ Edition and 31.7 Å per mm in the $7^{th}$ Edition. From this, you can calculate the redshift of each galaxy in Å. Write the answers in column 7 of the table. (5 points)

The velocity in km/s is equal to the redshift in Å divided by the rest wavelength of the Ca lines and multiplied by the speed of light. The average rest wavelength of the lines is 3950 Å. The speed of light is 300,000 km/s. Calculate the velocity of each galaxy in km/s and write the answer in the last column of the table (5 points) You might want to compare your answers with the values given in the figure, but – again – don't cook your measurements to get those numbers. Please do your best to measure them directly.

Now you can plot a "Hubble diagram" showing how quickly the Universe is expanding. Make a plot of velocity in km/s against distance in Mpc. (5 points)

This plot shows that more distant galaxies are moving away from us with faster velocities. Draw the best straight line that you can through the collection of points. You will find that they are not in a perfect line, partly because of measurement errors (our procedure is pretty crude) and partly because there is no guarantee that the pictures are exactly the same in exposure time and magnification. Just draw the best average line you can. **Make sure that it goes through zero velocity at zero distance.** (5 points)

You can now calculate the Hubble constant, that is, the number of km/s of velocity per Mpc of distance. You can get this from any point on the line. Be sure to keep the units, which are km/s/Mpc.

**The Hubble constant is:** (7 points)

Now you are ready to estimate the age of the Universe. This is, roughly speaking, the time that it has taken each galaxy to get to its present distance from us at its present velocity. Why? Because the Universe began in a Big Bang, when everything (including us and all of the present four galaxies) were together in one place. So the age is given, for example, by the distance you have gone if your velocity is 50,000 km/s divided by 50,000 km/s. In other words, the age of the Universe is approximately 1/(Hubble constant). Calculate the age of the Universe in years. Use the average line that you drew, not any individual cluster – this gives you a more accurate answer. You need to know that 1 pc is $3.09 \times 10^{16}$ m and that 1 year is $3.16 \times 10^{7}$ seconds (you can figure this out for yourself). In this part of the homework, the main thing to watch out for is units: make sure that you carry the units through every step of your calculation. The answer is:

**The age of the Universe is:** (8 points)

The true age is slightly shorter if there is enough matter in the Universe to slow down the expansion. But you should get within a factor of 2 of the right answer. It's not every day that you can calculate the age of the Universe to a factor of two! Astronomers do it essentially the same way that you have done it, only they use many more spectra and they use more accurate measuring machines (or computer programs).

B. Exam-style multiple-choice questions. For each question, circle the correct answer. (5 points each)

1. In the Milky Way galaxy, young stars – including the Sun – have orbits that
   (A) are nearly circular in the disk of the Galaxy.
   (B) slowly spiral in to the center of the Galaxy.
   (C) slowly spiral out to the outside of the Galaxy.
   (D) are random but confined to the disk plane.
   (E) are randomly oriented.

2. Which of these is correct?
   (A) The Milky Way looks almost uniformly bright around the sky, so we must be at the center.
   (B) The center of the Milky Way is visible through an eyepiece at a large telescope.
   (C) The Sun is one of the oldest stars in the Milky Way.
   (D) We live in the suburbs of the Milky Way; the Sun is an average star among billions.
   (E) The Milky Way is a 2-armed spiral; we can't see that because we live inside it.

3. According to the Hubble classification scheme, an Sc galaxy has
   (A) a large central bulge and tightly wound spiral arms.
   (B) a small central bulge and loosely would spiral arms.
   (C) a round or elliptical appearance with a smooth light distribution.
   (D) an irregular shape with no obvious spiral arms.
   (E) a featureless disk embedded in an almost spherical, smooth halo.

4. According to the Hubble classification scheme, an S0 galaxy has
   (A) a large central bulge and tightly wound spiral arms.
   (B) a small central bulge and loosely would spiral arms.
   (C) a round or elliptical appearance with a smooth light distribution.
   (D) an irregular shape with no obvious spiral arms.
   (E) a featureless disk embedded in an almost spherical, smooth halo.

5. Which of these **is not** a good tracer of spiral structure?
   (A) young stars
   (B) star-forming molecular clouds
   (C) globular clusters
   (D) cool hydrogen gas
   (E) 20 $M_\odot$ stars

6. If star formation switched off in a spiral galaxy, which part of it would get fainter?
   (A) the bulge
   (B) the disk
   (C) the halo
   (D) the dark matter
   (E) the globular cluster distribution

7. What is the essential difference between the formation of spiral and elliptical galaxies?
   (A) Random motions of stars are larger in ellipticals.
   (B) Spiral galaxies had a more recent tidal encounter with another galaxy.
   (C) Ellipticals form stars before they collapse; spirals form stars after they collapse.
   (D) Spiral galaxies rotate faster.
   (E) Ellipticals had a more recent violent encounter with another galaxy.

8. Why – mainly – do people measure the redshifts of galaxies?
   (A) To find their distances.
   (B) To find out what kind of stars they contain.
   (C) To get big grants from the National Science Foundation.
   (D) To see whether they are ellipticals or spirals.
   (E) To measure their luminosities.

9. The Milky Way and the Andromeda Galaxy are moving toward each other at more than 50 km/s. What will happen when they collide?
   (A) If humans still exist, they will be wiped out.
   (B) Nothing: they will just pass through each other and fly apart unchanged, because stars are too far apart to collide.
   (C) Lots of fireworks: many stars in our Galaxy will collide with stars in Andromeda.
   (D) They will tidally distort each other and may stick together and form a giant elliptical galaxy.
   (E) Each will come out of the collision as a wreck – as an irregular galaxy.

10. The temperature of the background radiation is almost the same in all directions.
   (A) This is surprising, because the radiation from opposite directions in the sky is coming from places that are beyond each other's light travel horizon.
   (B) This is expected, because the Big Bang was a very homogeneous explosion.
   (C) This was a measurement error in early observations that are now discredited.
   (D) The statement is not true: the temperature shows large fluctuations all over the sky.
   (E) None of the above.